OGCM SIMULATIONS OF EQUATORIAL PACIFIC CURRENT AND TEMPERATURE TO ERS-1, FSU AND NMC SURFACE WINDS AND TO ASSIMILATION OF SUBSURFACE TEMPERATURE DATA

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ABSTRACT

The relative accuracies of three surface wind data products for the tropical Pacific Ocean during April 1992 to March 1994 were examined by analyzing temperature and current fields along the equator, which were simulated with an ocean general circulation model, Simulations were made with and without assimilation of surface and subsurface temperature data, Simulated currents were compared with observations at three sites(170°W, 140°W, 11 0°W) at the equator. Model-generated currents and temperatures indicated that the ERS-1 westward wind speeds were low compared to the FSU and NMC winds. With data assimilation, the agreement between simulated and observed currents was highest at 170°W and lowest at 110"W.

1 INTRODUCTION

information about the surface wind field over the tropical ocean is of primary importance for studies of month-to-month variations of current and temperature, and especially for studies of the El Niño and La Niña episodes in the tropical Pacific Ocean, One of the initial objectives of the Tropical Oceans Global Atmosphere (TOGA) Program was to increase the accuracy of the surface wind field. Halpern (1988) indicated that the number of wind reports from ships was too small to achieve a 1 m s^{-1} accuracy. Under the auspices of the TOGA Program, the numbers of wind reports from ships and moored buoys increased substantially. However, large ocean areas remained unsampled each month. Surface wind data products computed from satellite measurements and from numerical weather prediction (NWP) results have much less aliasing errors compared to in situ wind measurements, although the accuracies of satellite and NWP wind products arc questionable, which is tbc subject of the paper.

The representativeness of three wind data products, which were employed to force an ocean general circulation model (OGCM) of the Pacific Ocean, was determined with in situ upper ocean current measurements at three sites along the equator (170°W, 140°W, 11 0"W), which arc named "validation" sites. A fourth validation site at 0°165°E will soon be employed in the analyses. The vertical distribution of current was emphasized because advection of heat is important in redistribution of temperature in the equatorial zone, which Bjerknes (1966) first suggested to be a leading mechanism for on.set of El Niño. Surface wind velocity data products were: (1) the ERS-1 product, which was computed by Freilich and Dunbar (1993) from European Remote Sensing (ERS-1) satellite scatterometer measure.mcrm; (2) the Florida State University (FSU) product, which was created at FSU from ship and moored-buoy data only (Goldenberg and O'Brien, 198 1), and (3) the U.S. National Meteorological Center (NMC) operational surface. wind analyses, which assimilates ship and moored-buoy winds, cloud motion vectors, and many other variables into an atmospheric general circulation model.

No OGCM simulation of current is perfect (Halpern *et* al., 1995) and no wind data product is perfect (Halpern *et* al., 1994). One remedy of the imperfections of the OGCM and wind product is assimilation of subsurface temperature measurements. Simulated currents arc, therefore, representative of the composite influences from the OGCM, such as the mixing parameterization, the wind field, assimilation scheme for subsurface temperature, and the quality, quantity and geographical distribution of subsurface. temperature measurements. The assimilation scheme was a variant of the method described by Ji *et al. (1995);* the weight function was uniform with depth, which presumed that data and simulated value,.s were of equal importance and the difference was not related to the vertical temperature gradient, in contrast to that employed by Ji *et* al. (1995). Temperature and current data recorded at the validation sites were not used in the assimilation scheme.

A two-year period (April 1992- March 1994) was chosen because it was the longest integral number of annual cycles of ERS-1 data. The ERS-1 satellite was launched in July 1991, but it was not until March 1992 that the last calibration of the scatterometer was made. The analyses described herein will be extended to include a third year (April 1994- March 1995). During the time period of the comparative study, not many wind reports from the. approximate 60-element Tropical Atmosphere-Ocean (TAO) array (Hayes *et al.*, 1991), which was located throughout the Pacific between 8°S and 8"N, had been received at NMC in a timely manner from the Global Telecommunications System (GTS) for assimilation in the NMC forecast-analysis system. A subsequent investigation will analyze the influence of TAO moored-buoy wind reports.

2 RESULTS

2.1 Temperature

Without data assimilation, the ERS- 1 simulated sea surface temperature along the equator from 170°W to 95°W was higher than the other simulations, with differences reaching nearly 2 °C at 100"W (Figure 1A), indicating that the month] y mean ERS-1 easterly wind speeds were lower than those produced by FSU and NMC. This is consistent with an orthogonal regression analysis between ERS- 1 and TAO wind data. Comparison of monthly mean ERS - 1 and TAO wind measurements from April 1992- June 1994 revealed that the average monthly mean ERS - 1 westward wind speed was 1.3 m s^{-1} less than that of TAO; the number of monthly collocations was 404, the root-nwan-square (rms) difference was 1.7 m S-l, and the correlation coefficient was 0.88. Assimilation of surface and subsurface temperature data made the ERS - 1 simulated sea surface temperature almost equal to the NMC and FSU simulated values (Figure 1 B).

Along the equator, the 20 "C isotherm represents the middle of the thermocline, defined to be the depth interval between the 25 "C and 15 'C isotherms. East of 120°W, the depth of the ERS-1 simulated 20 °C isotherm no longer decreased, in contrast to the shoaling of the 20 'C isotherms simulated with FSU and NMC winds (Figure 2A). At 10OOW there was a 40-m depth difference between the ERS-1 thermocline depth and those computed with FSU and NMC winds. The reduced east- west slope of the ERS - 1 thermocline between the eastern and western Pacific and the. deeper ERS- 1 thermocline in the eastern Pacific compared to those simulated with FSU and NMC winds were consistent with the previous result that ERS- 1 westward wind speeds were low compared to the FSU and NMC wind products. Assimilation of subsurface temperature data made the ERS- 1 depth of 20 'C isotherm almost equal to the NMC and FSU simulated values (Figure 2B).

2.2 Current

Without data assimilation, the longitudinal distributions of zonal current along the equator between the surface and 300-m depth (Figures 3A and 3B; FSU simulations will bc shown elsewhere) were nearly independent of the wind data product. All displayed a 20- to 30-m thick SEC at 140°W, a thickening of the SEC westward of 140°W to 50 m at 165°E, a maximum EUC speed within about 0.1 m S-l (or 10%) of one another, eastward current at the surface from 140°E to 150°E, a longitude of the EUC core speed between 140°W and 130°W, and a depth of the EUC maximum sped of 80 m. That the ERS- 1 simulated vertical shear between the surface and the depth of maximum eastward current was about 25% smaller than that computed with NMC winds indicated ERS-1 westward wind speeds were less than those of NMC.

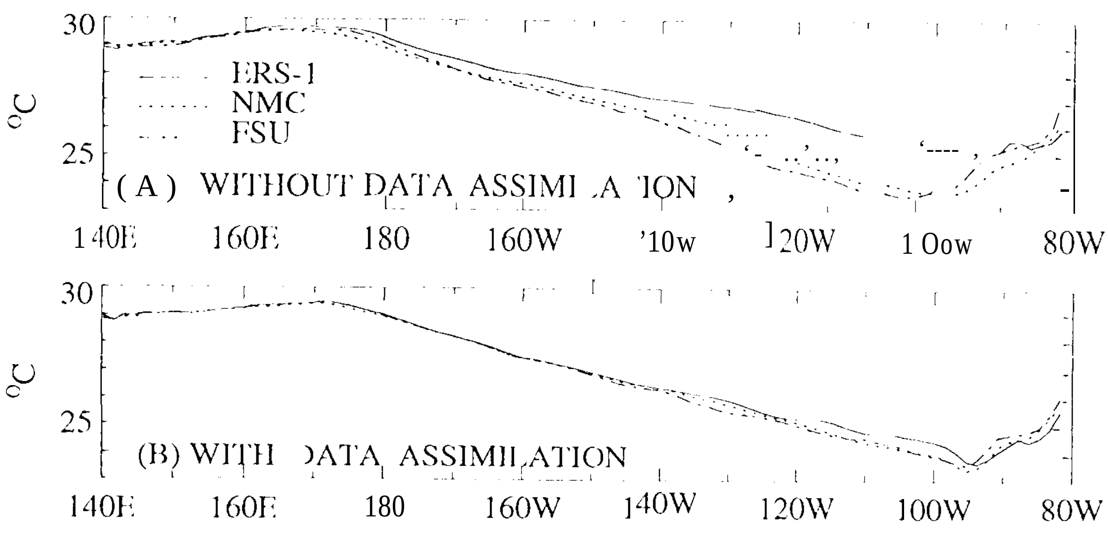

Figure 1. Two-year (April 1992- March 1994) mean sea surface temperatures along the equator simulated with an ocean general circulation model forced with three different surface wind fields (ERS-1, solid line; NMC, dotted line; FSU, dot-dash line), and (A) without data assimilation and (B) with assimilation of surface and subsurface temperatures.

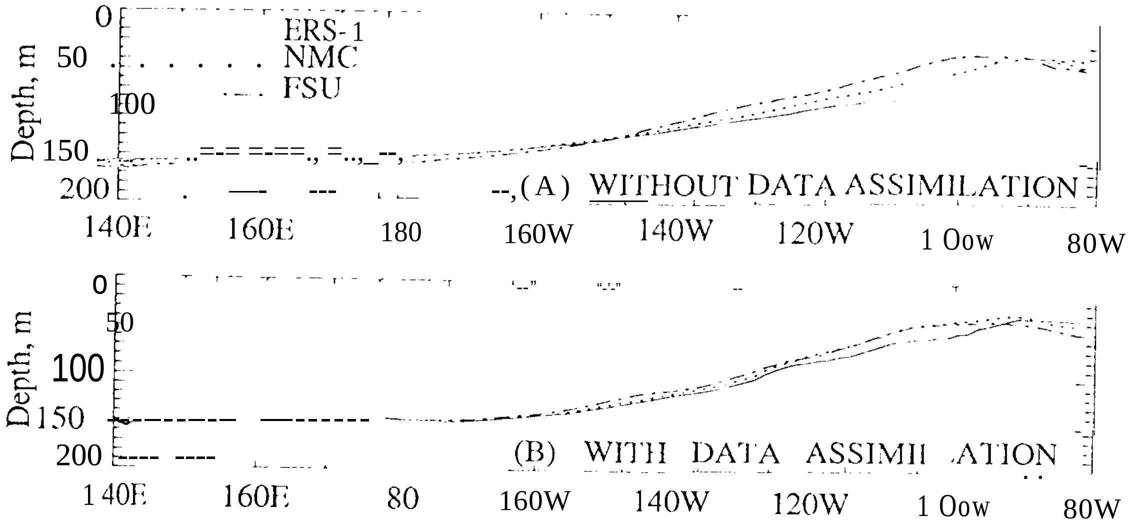

Figure 2. Two-year (April 1992- March 1994) mean depths of the 20 °C isotherm along the equator simulated with an ocean general circulation model forced with three different surface wind fields (ERS-1, solid line; NMC, dotted line; FSU, dot-dash line), and (A) without data assimilation and (B) with assimilation of surface and subsurface temperatures.

With assimilation of temperature data, notable differences appear between the simulated zonal currents (Figures 3C and 3D). The ERS-1 simulated EUC surfaced between 140°W and 100°W, in contrast to the FSU and NMC simulations which contained a SEC all along the equator. Simulated depths of the EUC were less, indicating an uplift of the EUC compared to simulations without data assimilation. The ERS-1 and NMC simulated EUC maximum speeds increased about 20% compared to the case of no data assimilation; no such change was associated with the FSU simulation. Apparently, data assimilation created a stronger ERS-1 EUC with a core depth closer to the surface, which, presumably, created an extensive surfacing of the EUC. The longitude of the EUC core speed shifted eastward about 10°. The SEC was stronger in the far western Pacific, e. g., no eastward current occurred from 140°E to 150°E, the SEC thickness at 165°E was about 90 m, which was twice as large as in the simulations without data assimilation, and the surface speed of the SEC at 165°E was about 0.4 m s^{-1} (or 400%) larger than that simulated without data assimilation. The appearance of a strong SEC (Figures 3C and 3D) is perplexing because at 165°E this feature was observed to occur during La Niña (T. Delcroix, personal

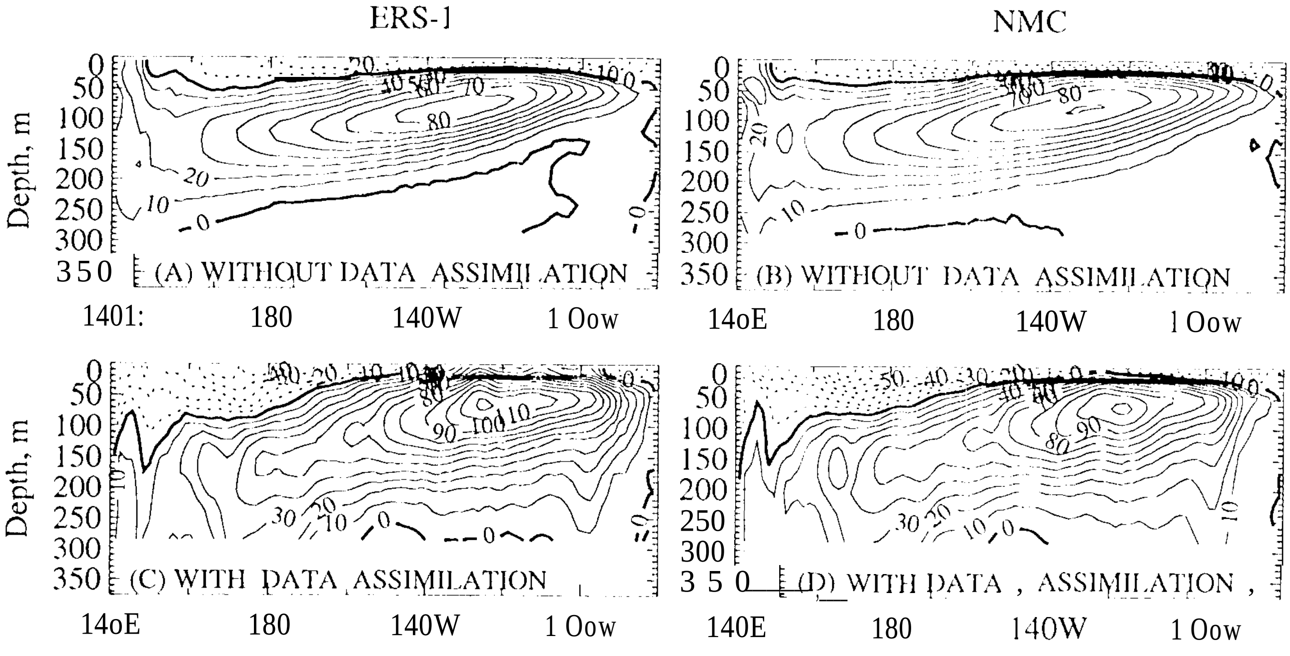

Figure 3. Longitudinal-depth sections along the equator of two-year (April 1992- March 1994) mean zonal current (solid line, direction towards east; dashed line, direction towards west) simulated with an ocean general circulation model forced with ERS-1 (right side) and NMC (left side) surface wind fields, and without data assimilation (upper) and with assimilation of surface and subsurface temperatures (lower).

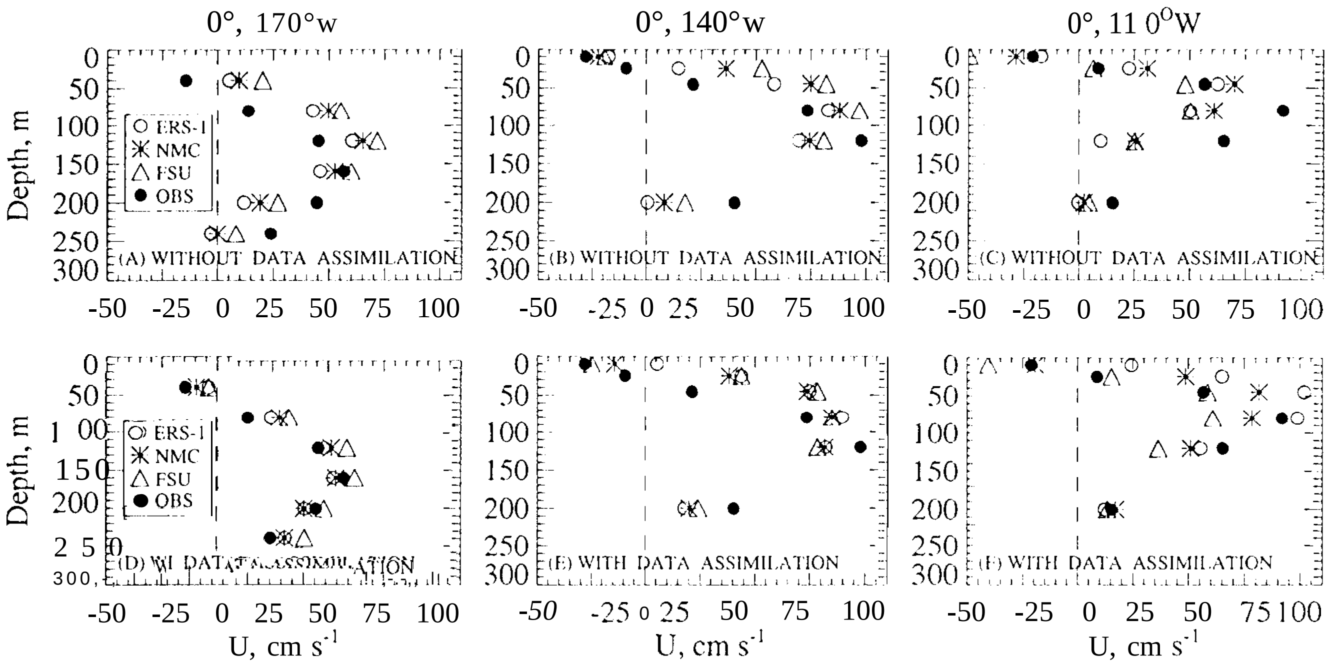

Figure 4. Vertical distribution of mean simulated and observed currents at 170°W (left), 140°W (center), and 110°W (right). Upper panel, without data assimilation; lower panel, with data assimilation. Simulated mean currents were computed only for the months associated with observations, and a monthly mean is equal to the mean computed for 20 or more days that a current meter recorded data during a calendar month. Positive values are eastward; negative values are westward.

communication, 1995), in contrast to the 1992-1994 El Niño. Between 140°E and 80°W and above 300 m, isolines of constant zonal current had more wiggles with data assimilation because of injection of subsurface temperature data at discrete locations, primarily at TAO sites where data are continuously assimilated in contrast to infrequent XBT data.

Simulated currents were compared with observations (Figure 4). All simulations contained the most prominent feature associated with equatorial circulation, which is a maximum eastward current at approximately 100-m depth. In accordance with the observations, the depth of the EUC core speed decreased towards the east, which was associated with the upward slope of the thermocline towards the east. Inspection of Figure 4 indicates that 170°W was the site of the best agreement between simulated and observed currents, and the agreement was improved with data assimilation.

Depth-averaged mean values of simulated and observed currents (Table 1) and depth-averaged rms differences between observed and simulated currents (Table 2) were employed to quantif y the results. Differences greater than 0.05 m S-l are considered significant because this quantity can easily be measured (Halpern, 1987).

The ERS-1 and NMC simulated mean currents at 170°W were practically indistinguishable from the observations (Table 1), and data assimilation had no substantial influence on the depth-averaged ERS - 1 or NMC simulated currents. At 140°W and at 11 0°W, all simulations of depth-averaged current, with and without data assimilation, were greater than 0.05 m S-l from observations.

The depth-averaged rms differences between observed currents and current'$ simulated with data assimilation at 170°W were about 0.07 m s^{-1} (24%) smaller than that computed with currents simulated without data assimilation (Table 2). At 140°W, therms differences between observed and simulated currents were not influenced by data assimilation for either of

Table 1. Depth-averaged mean currents computed from observations (OBS) and from simulations, without data assimilation (w/o DA) and with data assimilation (DA). Units = cm s^{-1}.

	170"W		140°W		110°W	
	OBS = 28.3		OBS = 26.2		OBS = 36.1	
	w/o DA	DA	w/o DA	DA	w/o DA	DA
ERS-1	27.2	30.1	34.7	52.2	?1.3	59.7
NMC	32.7	32.1	43.3	47,4	26.9	42.9
FSU	40.5	39.3	51.8	47.5	14.2	24.0

Table 2. *Depth-averaged rms difference between observed and simulated monthly mean currents without data assimilation (w/o DA) and with data assimilation (DA). Units = cm S-l.*

	170°W		140°W		110°W	
	w/o DA	DA	w/o DA	DA	w/o DA	DA
ERS-1	26.9	20.7	31.7	36.4	3s.8	41.7
NMC	27.9	20.5	37.8	40.1	28.5	27.1
FSU	30.6	23.8	43.3	40.7	34.4	29.7

the wind products. At 1 10°W, the rms differences between observed and simulated currents were not influenced by data assimilation for the FSU and NMC wind products, but assimilation reduced the agreement associated with ERS- 1 winds,

At 170°W and 140°W, therms differences between observed currents and currents simulated with data assimilation were considered independent of the type of wind data product. At 110"W, Therms difference between observed currents and NMC simulated currents with data assimilation was significantly smaller than those associated with ERS-1 and FSU winds; the rms difference associated with the ERS-1 winds was the highest.

3 SUMMARY

Assimilation of surface and subsurface temperature data produced simulated sea surface temperatures and depths of 20 °C isotherm that were independent of the wind data product (Figures 1B and 2B), which is not very surprising because temperature data were assimilated. However, without data assimilation the. simulated sea surface temperature and depth of 20 'C isotherm associated with the ERS - 1 winds were. not the same as those computed with FSU and NMC winds (Figures 1A and 2A), indicating that the ERS-1 westward wind speed was too low in the central and eastern equatorial Pacific.

Currents simulated with and without data assimilation contained the essential circulation characteristics of the SEC and EUC (Figure 3). However, assimilation of temperature data produced two features that are considered unrealistic: the SEC surface speed and SEC thickness in the western Pacific were believed to be too large (Figures 3C and 3D); and the surfacing of the ERS - 1 simulated EUC (Figure 3C), which was presumably caused by the weak westward ERS- 1 wind speed. Only at 170°W did data assimilation produce a substantial reduction in therms difference between observed and simulated currents (Table 2). With data assimilation, the agreement between simulated and observed currents was highest at 170°W and lowest at 11 O"W (Figure 4; Tables 1 and 2). The reason for the longitudinal variation in the agree.ment between simulated and observed currents will be discussed elsewhere.

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